EUV interference lithography with partially coherent laboratory sources

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Motivation

Recent progress in nanotechnology and a constant increase in requirements on nano-structures based devices in terms of integration density and energy efficiency is rapidly pushing feature sizes towards sub-10 nm dimensions. At the moment, high density structures on this scale are not only beyond what is possible with available mass production technology, but also not reachable with low-volume research oriented techniques, such as electron beam or ion beam writing [1].

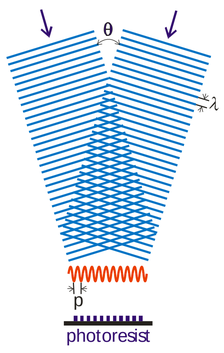
EUV nanostructuring

Interference lithography (IL) with extreme ultraviolet (EUV) radiation is the most promising technique to achieve the sub-20 nm resolution for large and dense arrays of periodic nanostructures [2]. Thanks to the short wavelength (typically between 10 nm – 15 nm) structuring with EUV light on a scale of a few tens of nanometers is not limited by diffraction. And, in contrast to high energy techniques, proximity and charging effects are negligible due to the very strong interaction of EUV radiation with matter leading to short (<100 nm) absorption distances.

Furthermore, the combination of top-down pre-patterning via EUV-IL with bottom-up self-assembly is of special interest as it is not only an innovative research instrument but also highly suitable for large-scale production [3].

Test exposure results address a number of perspective applications of the technique including cross-bar arrays for phase change memories, nano-photonic components and substrate pre-patterning for self-organized growth of ordered quantum dots.

EUV interference lithography



Large-area periodic structures

Large depth of focus

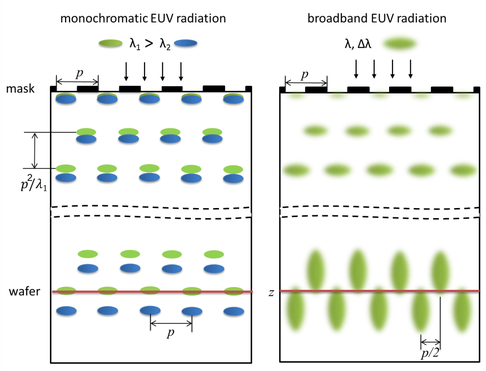
Requires a coherent light

Low cost – no complicated and expensive optics

Ultimate resolution for the wavelength (~λ/4)

EUV: λ = 11 nm ➡ feature size: ~3 nm

Structure size and period reduction utilizing interference effects



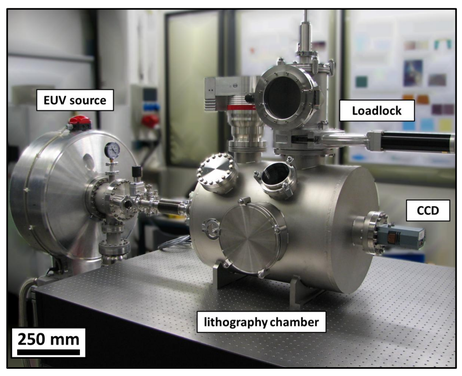
$$L_{Talbot} = \frac{2p^2}{\lambda}$$

Self images of the grating at distances proportional to Talbot distance

For not perfectly monochromatic light Talbot self images mix and form a stationary image with half of the grating period at a distance z [4,5] .

Lithography setup at RWTH/ILT

EUV-IL exposure setup with a high power DPP EUV source

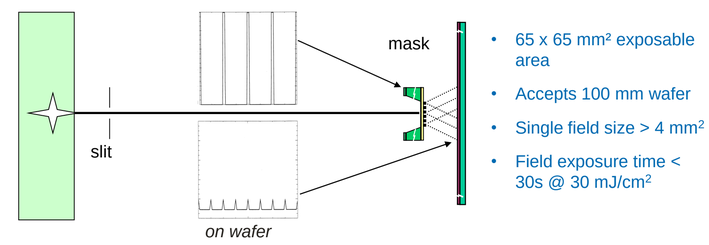


EUV nanostructuring system for proximity and interference lithography of 100 mm wafers with sub-10 nm resolution.

Wafer-mask control with nanometer precision.

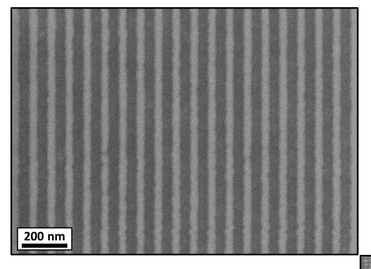
Over 1 mm² area can be structured in a single exposure.

Minimum optical components to reduce power loss.



- 65 x 65 mm² exposable area
- Accepts 100 mm wafer
- Single field size > 4 mm²
- Field exposure time < 30s @ 30 mJ/cm²

Exposure results & applications

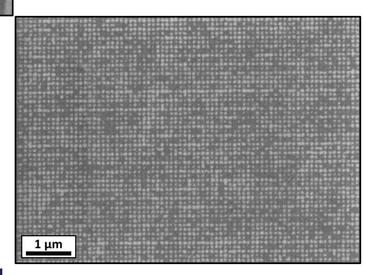


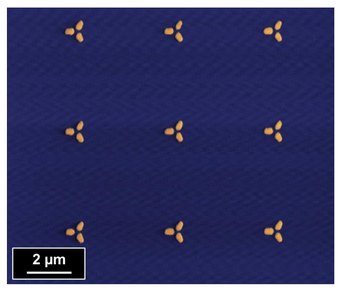
High quality 100 nm L/S array written in ZEP resit by EUV proximity printing.

Next-Gen Quantum Dot LED und Laser.

Pinhole array produced by double exposure with L/S mask in achromatic Talbot mode.

The dot patterns with 100 nm period written in ZEP resist by EUV-IL. The diameter of the pinholes is ~40 nm.

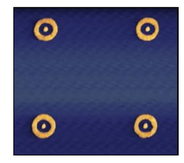


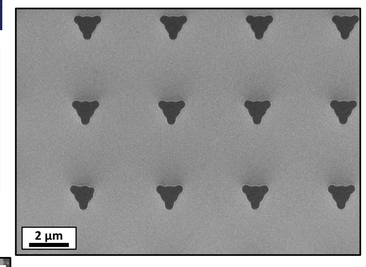


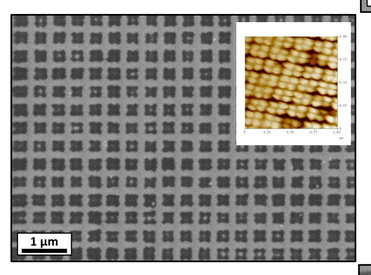
Nanophotonic components

Nanoantenna arrays produced with proximity lithography.

Proximity printing in the Fresnel diffraction mode enables production of high resolution features even with lower resolution masks







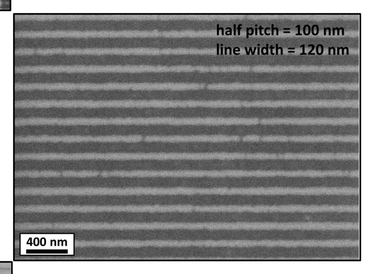
Next-generation storage media

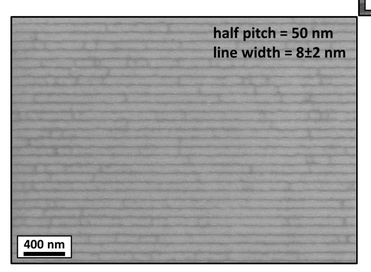
Crossbar arrays for PCRAM done by double exposure with L/S mask in contact.

Inset shows Ge quantum dot growth on pre-patterned substrate.

Proximity structures: one-to-one replication of 100 nm half pitch transmission mask with EUV proximity printing.

EUV proximity lithography generates 1:1 copy of transmission mask…

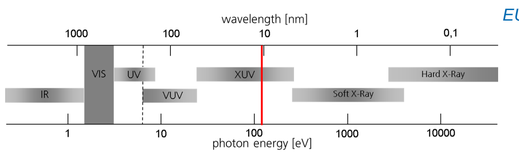




…but EUV lithography in achromatic Talbot distance leads to period and feature size reduction.

Talbot structures: sub-10 nm structures with 50 nm half pitch obtained with EUV interference lithography with 100 nm half pitch transmission mask

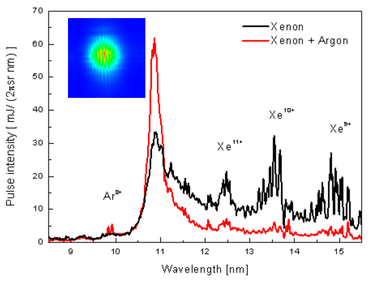
EUV gas discharge source



EUV spectral range

EUV source: plasma-based gas discharge EUV radiation source developed at Fraunhofer ILT

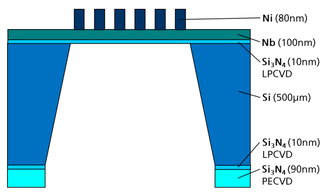
- *compact 2 kHz source*
- *input power 5.6 kW*
- *pinch radius 100 µm*
- *100W/(mm²sr) radiance @ 1 10.9 nm*

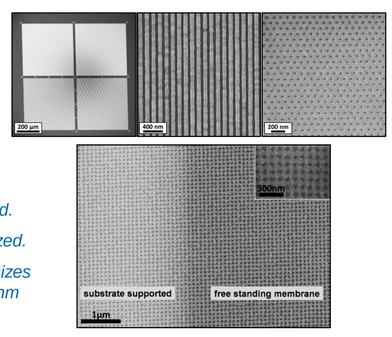


Broadband emission spectra of Xe/Ar discharge produced plasma EUV source.

Source emission was optimized to achieve highest possible intensity within the necessary bandwidth [6].

Masks & simulations



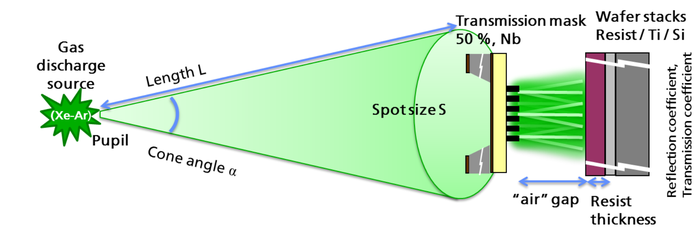


New niobium-based technology developed.

Flat membranes with > 1 mm² area realized.

Lines and pinholes arrays with structure sizes down to 40 nm and periods down to 100 nm are realized.

Lithography simulations (Dr. Litho)



Source	Mask	Resist
✓ Wavelength	✓ Absorber	✓ Stack, Resist parameter (Dill ABC)
✓ Bandwidth	✓ Transmittance	✓ Exposure time
✓ Pupil shape	✓ Scalar diffraction models (Kirchhoff, RS I, RSII)	✓ PEB time, temp. (Diffusion)
✓ Cone angle	✓ Rigorous diffraction simulation	✓ Develop time (Mack parameter)
✓ Polarization		✓ Resist profile (Process windows)

Conclusion

- EUV Interference lithography is a powerful tool for cost efficient patterning of nanoscale periodic arrays
- Optimized high power gas discharge source can be effectively used as a source for EUV-IL
- Talbot lithography is the most efficient solution for nanopatterning with sources of limited coherence.
- Nb-based transmission masks can be used as an universal solution for interference lithography with wavelength between 6 and 15nm
- The resolutions down to sub-10nm are possible, limited by mask quality and resist performance

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